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20. Since previous saturation dives have caused loss of body weight despite apparently adequate to high food intake, a complete study of energy balance was undertaken during the saturation dive called Hana Kai II. Over a 30-day period in the hyperbaric chamber (3 days of predive control, 1 day of compression, 16 days at 18.6 ATA, 7 days of decompression, and 3 days of postdive control), all food, urine, and feces for five men were analyzed by bomb calorimetry; 24-hour energy expenditure (M) was measured from continuous $\dot{V}O_2$, $\dot{V}CO_2$ and urine N; body weight was taken daily; body composition was assessed from density, total body water, and skinfold thickness. Food intake was high throughout the 30 days, about 3500 kcal/day, while fecal and urinary losses were a normal 6-8% of intake; M was increased a little by the hyperbaric condition, but averaged only 2431 kcal/day for the 30 days, yet there was an average loss of adipose tissue of 0.8 kg. Nitrogen balance was positive. There was no evidence of heat gain or loss. The energy balance--total fuel compared with energy expenditure--required an additional 919 kcal/man-day for 30 days, an unidentified term which is not measured by conventional techniques.

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ENERGY BALANCE IN SATURATION DIVING

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ABSTRACT

Since previous saturation dives have caused loss of body weight despite apparently adequate to high food intake, a complete study of energy balance was undertaken during the saturation dive called Hana Kai II. Over a 30-day period in the hyperbaric chamber (3 days of predive control, 1 day of compression, 16 days at 18.6 ATA, 7 days of decompression, and 3 days of postdive control), all food, urine and feces for five men were analyzed by bomb calorimetry; 24-hr energy expenditure (M) was measured from continuous $\dot{V}O_2$, $\dot{V}CO_2$, and urine N; body weight was taken daily; body composition was assessed from density, total body water, and skinfold thickness. Food intake was high throughout the 30 days, about 3500 kcal/day, while fecal and urinary losses were a normal 6-8% of intake; M was increased a little by the hyperbaric condition, but averaged only 2431 kcal/day for the 30 days, yet there was an average loss of adipose tissue of 0.8 kg. Nitrogen balance was positive. There was no evidence of heat gain or loss. The energy balance -- total fuel compared with energy expenditure -- required an additional 919 kcal/man-day for 30 days, an unidentified term which is not measured by conventional techniques.

Index terms:
Weight loss, total body water, metabolism, nitrogen balance, food intake, energy expenditure, oxygen consumption, carbon dioxide production, fecal losses, urine losses, body composition, convective heat transfer coefficient.

ENERGY BALANCE IN SATURATION DIVING

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Men under saturation diving conditions lose weight despite adequate to high food intake (Webb 1970, 1973). In 14 of 15 saturation dives where body weight has been measured, most subjects lost weight; in the 15th there was no weight loss. Calorie counting of food intake was done in six of these studies and the intake was reported to be 2500-3500 kcal/day. In the other nine studies, food intake was said to be between 3500 and 6000 kcal/day. Despite the high food consumption, weight losses of 0.6 to 4 kg were observed in 14 dives. This information is summarized in Table 1. Figure 1 is a graph of weight loss versus hyperbaric exposure with a regression line for 13 of the studies where temperatures were kept comfortably warm during the dive.

There are several plausible explanations for the persistent weight loss during saturation diving. The most likely seem to be:

1. Caloric deficit caused by increased energy expenditure.
2. Loss of body water.
3. Atrophy and tissue loss from confinement.
4. Caloric deficit from poor absorption of food.
5. Some unidentified error in the caloric balance data-- e. g. an overestimation of the caloric value of food taken.

Table 1. Weight loss in saturation diving as a function of the depth and duration of the dive. Pressure is shown in absolute terms (ATA), but pressure exposure is the product of gage pressure in atmospheres times days at depth, omitting compression and decompression periods.

	Gas mix --pressure gas - ATA	Duration at depth days	Pressure exposure atm · days	Mean weight loss kg	Mean food intake kcal/day	Number of subjects
Helgoland (North Sea)	air - 3.3*	10	23	4	6000	9
Tektite II (Caribbean)	air - 2.3	14 - 21	27	2.0	>3500	53
U. Hawaii	HeO_2 - 16.1	2	30	0.6	>4000	6
JAMSTEC	HeO_2 - 7	7	42	0.0	2900**	3
Tektite I (Caribbean)	air - 2.15	60	69	1.6	ad lib	4
Genesis E	HeO_2 - 7	12	72	0.6	4200	3
SeaLab II (Bermuda)	HeN_2O_2 - 7.2	15	93	2	>4000	28
Aegir (offshore Hawaii)	HeO_2 - 16.6*	6	94	2.9	ad lib	6
U. S. Navy, EDU	HeO_2 - 19.2	8	146	1.2	ad lib	7
Sagittaire II	HeO_2 - 49	4	192	1.5	2500	2
U. Hawaii (present study)	HeO_2 - 18.6	16	282	0.8	3440	5
U. S. Navy, EDU	HeO_2 - 49.5	7	340	3.5	2900	6
U. Penna.	HeO_2 - 13, 24, 28, 37	17	441	4.0	3510	4
Sagittaire III	HeO_2 - 31	15	450	2.4	2580	4
Sagittaire I	HeO_2 - 31	17	510	2.4	2850	4

*Cold exposure during the dive.

**Underlined values measured by dietary techniques (others estimated).

Note: Those dives that took place at sea have the water location in parentheses; others are dry chamber simulations.

Sources:

Helgoland: Uhlig & Haux (1972)
Tektite II: Beckman & Smith (1972)
U. Hawaii: Moore et al.(1974)
JAMSTEC: Matsuda et al.(1975)
Tektite I: Webb (1970)
Genesis E: G. E. Bond (personal communication)
SeaLab II: Webb (1970)
Aegir: Pegg (1971)
U. S. Navy, EDU: Uddin et al.(1971)
Sagittaire I, II, and III: X. Fructus (personal communication)
U. S. Navy, EDU: Raymond et al.(1975)
U. Penna: Puglia et al. (1976)

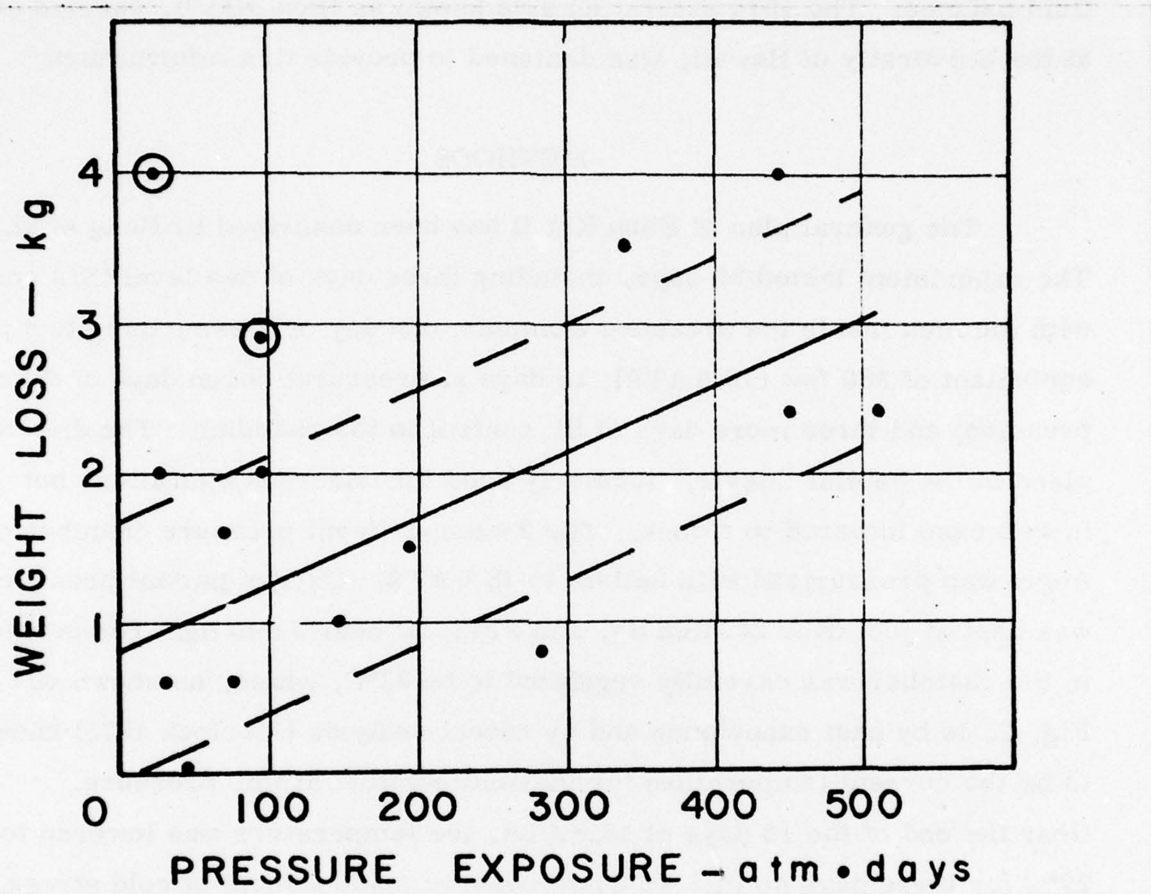

Figure 1. Average weight losses of men in saturation dives as a function of the product of gage pressure in atmospheres and days of exposure. A regression line with its standard error is shown for 13 of the dives ($y = 0.81 + 0.00448x$, ± 0.84, $r = 0.68$). Two dives, marked with circled points, were not included since they involved strong cold stress, which seems to increase the weight loss for a given pressure exposure. Sources and more information are given in Table 1.

To determine what causes the weight loss requires a careful accounting of all the elements of the energy balance accompanied by an accounting of fluid balance. The 1975 saturation dive known as Hana Kai II, carried out at the University of Hawaii, was designed to provide this information.

METHODS

The general plan of Hana Kai II has been described by Hong et al. (1975a). The experiment lasted 30 days, including three days of sea level (SL) control with the men inside the pressure chamber; one day of pressurizing to a pressure equivalent of 580 fsw (18.6 ATA); 16 days at pressure; seven days of decompression; and three more days of SL control in the chamber. The dive took place in the habitat "Aegir," formerly used for undersea operations but in this case tethered to a dock. The 3-compartment pressure chamber of Aegir was pressurized with helium to 18.6 ATA. Oxygen partial pressure was kept at just over 200 mm Hg, and P_{CO_2} at near 2 mm Hg. Temperature in the chamber was carefully regulated to be 31°C, which, as shown on Fig. 2, is by past experience and by recent analysis (Morlock 1975) known to be the correct temperature for thermal comfort at this pressure. Near the end of the 16 days at 18.6 ATA, the temperature was lowered to 27°C for three days so that we could observe some effects of cold stress.

Energy Balance Calculation

Over the 30-day experimental period, the energy balance was considered to take the following form:

energy in = energy out (1)

energy in = total fuel (2)

total fuel = calories in food ingested - calories in feces - calories in urine + calories from body stores (3)

energy out = metabolic free energy conversion (4)

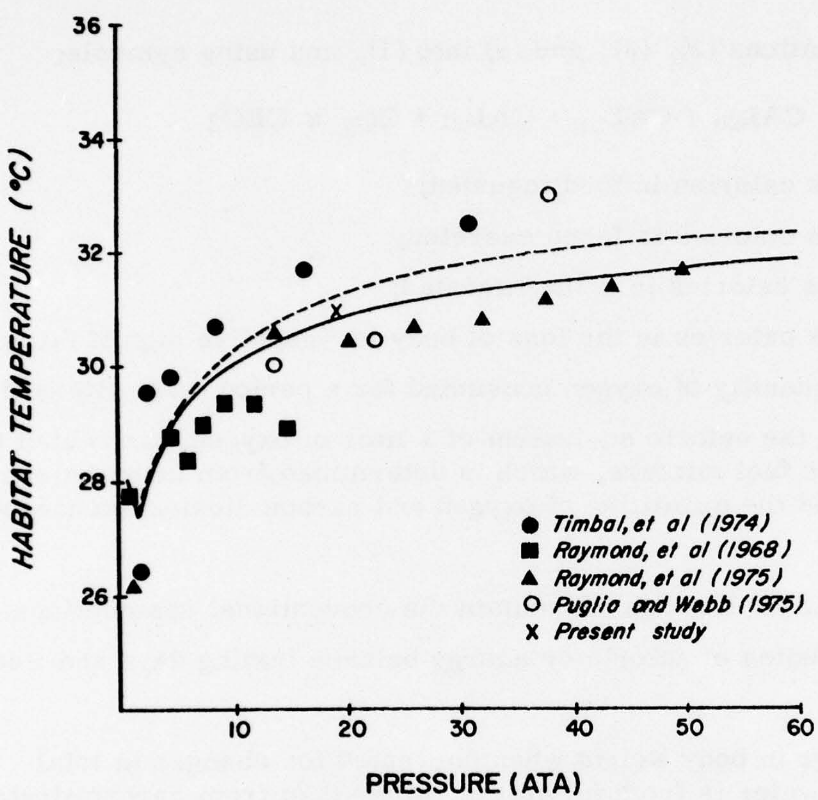

Figure 2. Comfort temperatures for prolonged stay in hyperbaric helium. Two prediction curves are shown from Morlock (1975), along with empirically found temperatures from a number of saturation dives. The solid line predicts comfort temperature (equivalent to 28°C in air at 1 ATA) as a function of pressure if the Reynolds number of the gas is between 4 and 40, while the dashed line makes the same prediction if the Reynolds number is between 4000 and 40,000.

metabolic free energy conversion = oxygen consumption x caloric equivalent of O_2 (5)

Substituting equations (2), (3), and (5) into (1), and using symbols:

$$CAL_{fd} - CAL_{fe} - CAL_{ur} + CAL_{st} = QO_2 \times CEO_2 \tag{6}$$

where: CAL_{fd} is calories in food ingested;

CAL_{fe} is calories in feces excreted;

CAL_{ur} is calories in urine excreted;

CAL_{st} is calories in the loss of body fat (negative sign if fat is stored);

QO_2 is quantity of oxygen consumed for a period (e.g. liters/day);

CEO_2 is the caloric equivalent of 1 liter of oxygen, corrected for the fuel mixture, which is determined from nitrogen excretion and the quantities of oxygen and carbon dioxide exchanged.

Equations (2) through (6) contain the conventional assumptions used in nutritional studies of caloric or energy balance lasting days and weeks, namely that:

a. change in body weight when corrected for changes in total body water is from fat stores rather than from carbohydrate stores, especially if there is no evidence of significant loss or gain of tissue protein;

b. the efficiency of food utilization once it has been digested does not vary significantly between people;

c. all of the energy expenditure is aerobic and known from oxygen consumption; and,

c. there is no accumulation of either energy losses or gains such as, for example, heat storage in the body, or major change in ATP stores.

Measurements

1. Caloric exchange measurements.

Food intake. Every item of food sent in to each of the five subjects was weighed, and when trays or containers were sent back out of the chamber, each item of waste was identified and weighed. This gave a complete record of all food and liquid actually consumed. Samples of every food item were set aside, frozen, and later analyzed for caloric content in an oxygen bomb calorimeter (Parr Instrument Co.) at the Naval Medical Research Institute (NMRI). From the record of food ingested and the data on caloric value of each item, caloric intake was computed for each man for each day of the experiment.

A mixed diet chosen for palatability was prepared daily from largely fresh ingredients. Breakfast, lunch, supper, and two snacks were offered, with no limits on quantity. Coffee and tea were not allowed, but fruit juice, milk, and decaffienated coffee were freely available. Food items were of the type commonly eaten in the United States, plus a number of items characteristic of Hawaiian residents, i. e. of Oriental nature. The protein content of the diet averaged 127 gms/day, which is more than adequate.

Feces and urine excreted. All feces were collected in plastic bags, frozen, and sent to NMRI for bomb calorimetry, where each man's output for each 3-day period was pooled, and an aliquot analyzed for caloric content. Twenty-four hour urine collections were completed daily for each man. An aliquot of each collection was frozen and sent to NMRI for bomb calorimetry.

2. Body composition measurements

Body weight, skinfolds, and circumferences. All subjects were weighed on a platform balance, with an accuracy of ± 10 gms, each morning between 0600 and 0700 hours, after voiding but before eating or drinking. Reported

weights have been corrected for the change in buoyancy that results from the increased density of the hyperbaric gas. The buoyancy calculation comes from summing the densities of the different components of the hyperbaric mixture in proportion to their percentage of the mixture (He 92.28%; N_2 5.84%; O_2 1.64%; water vapor and CO_2 negligibly small) times the total pressure, then correcting for temperature. This gave a density of the gas at 18.6 ATA and 31°C of 4.3580 gm/L. Since air at 1 ATA and 31°C has a density of 1.1765 gm/L, the difference is 3.1815 gm/L. This last value was multiplied by the body volume of each subject in liters (known from underwater weighing), giving weight corrections for the 18.6 ATA condition as follows:

Subject	Correction (kg)
JM	.206
BR	.210
JD	.242
RS	.188
EH	.215

Skinfolds were measured with Lange calipers daily at nine body sites on each subject. The nine values were added together to give a single number for the total. Torso circumferences were measured every three days at two sites: chest circumference at the level of the xiphoid cartilage, and abdominal circumference at the level of the iliac crest.

Body density. Subjects were weighed in air and under water (at full exhalation), and residual lung volumes determined by the N_2 washout procedure of Wilmore (1969). Body density and the percent of body fat were then calculated by the procedure of Brozek et al. (1963). The procedure was done the day before the first day of predive sea level control, and again the day following the last day of postdive sea level control.

Total body water (TBW). Using the non-invasive deuterium oxide procedure of Wang et al. (1973), TBW was measured in all five subjects before and after the dive, and at middive on day 13. Subjects drank D_2O at night on retiring, then overnight urine and two subsequent samples were collected. Urine samples were frozen and sent to NMRI, where they were purified by vacuum distillation, then analyzed for D_2O by infrared spectroscopy.

3. Metabolic measurements

Oxygen consumption and CO_2 production. Two completely independent methods were employed for this measurement. The first was an adaptation of the standard method of collecting expired air for three minutes in a Douglas bag (in this case, in a weather balloon), measuring its volume, and analyzing for gas composition. Expired volume was measured using a Parkinson-Cowan dry gas meter inside the hyperbaric chamber. The dry gas meter was calibrated at sea level and at 18.6 ATA against a Tissot type gasometer. Then a sample of the bag of mixed exhaled air was passed through pressure reducing valves to the outside, where composition was determined by gas chromatography (Quinton, Model R). Calibrating gases were analyzed by the micro Scholander technique. Standard calculations gave values for $\dot{V}_{O_2}$ and $\dot{V}_{CO_2}$. Four of the five subjects were each measured four times a day (the fifth subject had other duties to perform), while seated at rest, for all 30 days. Times of collection were 0630, 1030, 1530, and 1930.

The second method was developed especially for saturation dives during which a full accounting of metabolic expenditure is wanted. The method permitted near-continuous 24-hr monitoring of $\dot{V}_{O_2}$ and $\dot{V}_{CO_2}$ on one man each day. Four subjects were studied, the same four whose resting levels were measured by the standard technique just described. For continuous monitoring, the man wore a lightweight plastic facepiece that sealed lightly around the forehead, cheeks, and chin (Webb and Troutman, 1970). Chamber gas was drawn by a small motor-blower through this facepiece at a calibrated rate of 100 L/min. This flow rate, plus the 3 L volume of the facepiece, insured that all exhaled air would be drawn down the hose to the blower, along with ambient gas. Gas sampling lines were located at the top of the

facepiece (at the gas intake) for inspired gas, and at the blower intake for mixed exhaled and ambient gas. These two gas samples were led outside the chamber to sensitive differential gas analyzers, as shown in the system diagram, Fig. 3. The facepiece and blower, with connecting cable and sample lines, allowed the subject to move freely about the laboratory section of the hyperbaric chamber, so that during the day he was able to perform his usual duties. At night he slept in the same area on a cot or hammock.

The difference in oxygen partial pressure before and after the subject was detected by a differential fuel cell oxygen analyzer (Applied Electrochemistry, Model N-39M), which had a maximum sensitivity of 0-500 ppm full scale (0.05% full scale), while the difference in CO_2 level before and after the subject was detected by a differential infrared CO_2 analyzer (Beckman, Model 865), which also had a sensitivity of 500 ppm full scale. The signals from the gas analyzers were fed into a signal amplifier where special circuits continuously computed $\dot{V}O_2$ and $\dot{V}CO_2$ in STPD L/min. These two rates were then totalized for 10-min periods, and the result printed on a paper tape.

System calibrations of the continuous method were done at sea level and at 18.6 ATA. The method was as previously described (Webb and Troutman, 1970), in which an inert gas (CO_2 in this case) injected into the facepiece (while it is not being worn) simultaneously checks blower volume flow, the response of the two gas analyzers, and the conversion of the ΔPO_2 and ΔPCO_2 signals into $\dot{V}O_2$ and $\dot{V}CO_2$.

While being measured, subjects wore the facepiece day and night, removing it only for meals, or for the resting measurement of $\dot{V}O_2$-$\dot{V}CO_2$ by collection, or for other occasional duties outside the laboratory section of the chamber. Continuous metabolic measurements were made during 18 of the 30 experiment days; on the average, 60% of each such day was measured. There were 1498 10-minute periods recorded. No continuous measurements were made during the day of compression or the seven days of decompression. Each subject wore the monitor at least once at sea level, and two or three times at 18.6 ATA warm. During the three days at 18.6 ATA cold, the four

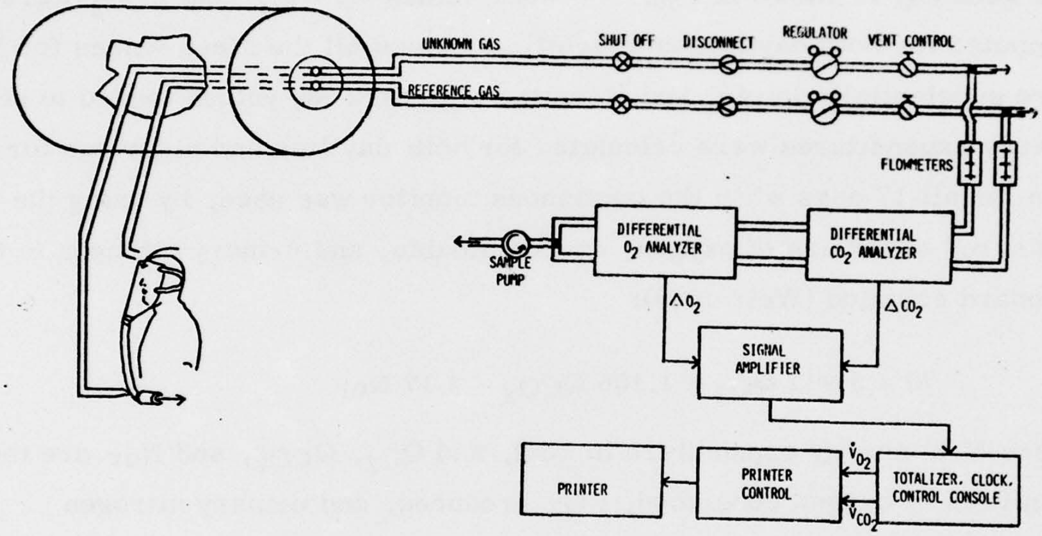

Figure 3. **Block diagram of the system for continuously determining $\dot{V}_{O_2}$ and $\dot{V}_{CO_2}$ from a subject in a hyperbaric chamber.**

men took turns with the facepiece in 4-hr rotating shifts, except at night, when one of the subjects slept in it for eight hours.

Because the data from continuous monitoring was voluminous, it was entered on IBM cards for further manipulation. Each day was machine plotted as a series of points for 10-min averages of $\dot{V}_{O_2}$ and $\dot{V}_{CO_2}$. One such day is shown in Fig. 4. Mean values for $\dot{V}_{O_2}$ and $\dot{V}_{CO_2}$ were computed for both daytime and nighttime, since all the sleep values for $\dot{V}_{O_2}$ were substantially lower, and since the nighttime RQ values tended to be higher. Energy expenditures were calculated for both daytime and nighttime for each man for all 17 days when the continuous monitor was used, by using the measured quantities of oxygen, carbon dioxide, and urinary nitrogen in the standard equation (Weir 1949):

$$M = 3.941\ Q_{O_2} + 1.106\ Q_{CO_2} - 2.17\ N_{ur} \qquad (7)$$

where M is energy expenditure in kcal, and Q_{O_2}, Q_{CO_2}, and N_{ur} are the quantities of oxygen consumed, CO_2 produced, and urinary nitrogen excreted over the period.

4. Temperature measurements

In addition to the above measurements to determine caloric balance, there were daily measurements of the variables needed to calculate heat losses. Thus skin and rectal temperatures were taken on four subjects four times a day; environmental gas temperatures, globe temperatures, and humidity were monitored; and insensible weight loss was measured overnight and for 8-hr periods in the daytime.

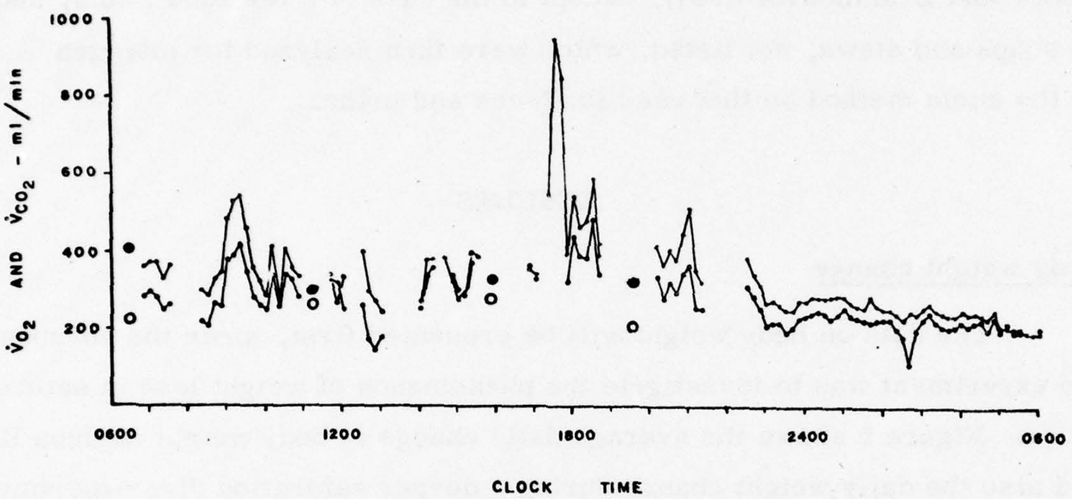

Figure 4. Oxygen consumption ($\dot{V}O_2$) in solid circles and carbon dioxide production ($\dot{V}_{CO_2}$) in hollow circles for subject BR for 24 hours starting at 6:00 AM on dive day 13, at 18.6 ATA and 31°C. Each point is the average rate from a 10-minute continuous measurement. Peak values for $\dot{V}O_2$ between 1700 and 1800 hours were caused by bicycle exercise voluntarily taken. Large symbols at 0630, 1110, 1540, and 1930 hours show the values obtained by the bag collection method, while the subject was seated.

5. Nitrogen balance measurements.

Nitrogen content of feces and 24-hr urine collections was determined by a semimicro Kjeldahl method at NMRI. Nitrogen content of foods eaten was found in handbooks on the composition of food (Bowes and Church 1970; Miller and Branthoover 1957), except in the case of a few food items, such as soups and stews, not listed, which were then analyzed for nitrogen by the same method as that used for feces and urine.

RESULTS

Body weight change

The data on body weight will be presented first, since the purpose of the experiment was to investigate the phenomenon of weight loss in saturation dives. Figure 5 shows the average daily change in body weight in Hana Kai II, and also the daily weight change during a deeper saturation dive experiment at the University of Pennsylvania in 1971 (Puglia et al. 1976). The values shown have not been corrected for changes in TBW. In Hana Kai II, TBW was, on the average, decreased by 0.45 kg at middive, but by the time of the postdive sea level control period it had increased by 0.79 kg, compared to predive control. Since average gross weight from predive control to postdive control did not change, there had in fact been a real weight loss of 0.79 kg, which was hidden by the overhydration. This 0.8 kg of weight loss is the value shown in Table 1 and in Fig. 1.

Notice in Fig. 5 that the greatest weight loss in Hana Kai II was reached toward the end of the 18.6 ATA period, and that there was considerable regain during decompression. But not only was regain evidently exaggerated by overhydration, the weight loss of the first days was increased by evident dehydration. These fluid shifts had to be allowed for in calculations of weight loss (fat loss)-- or gain in one man-- when estimating how much fuel store was expended in the various dive periods.

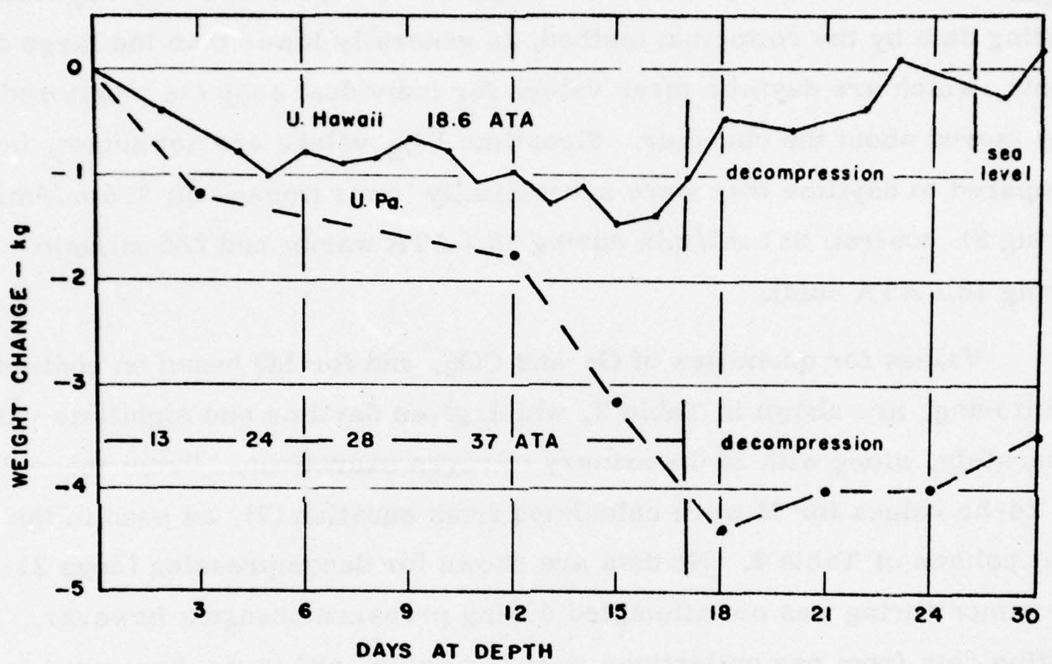

Figure 5. Average weight changes for five subjects in the present study (U. Hawaii) and for four subject in the 1971 University of Pennsylvania dive (Puglia et al. 1976). All weights have been corrected for the buoyancy change from increased gas density, but not for changes in total body water.

Energy expenditure

Figure 6 shows how the oxygen consumption values rose above sea level control levels during the days at 18.6 ATA, and how the three cold days (T_{gas} = 27°C) drove $\dot{V}_{O_2}$ higher than it was during the warm days (T_{gas} = 31°C). Notice that the solid line, which represents only daytime resting data by the collection method, is generally lower than the large data points, which are daytime mean values for individual subjects monitored as they moved about the chamber. Sleeptime $\dot{V}_{O_2}$ values are not shown, but compared to daytime they were substantially lower (means of: 265 ml/min during SL control; 281 ml/min during 18.6 ATA warm; and 286 ml/min during 18.6 ATA cold).

Values for quantities of O_2 and CO_2, and for RQ based on continuous monitoring, are shown in Table 2, which gives daytime and nighttime values separately, along with 24-hr urinary nitrogen excretions. From these data the 24-hr values for M were calculated from equation (7), as seen in the final column of Table 2. No data are shown for decompression (days 21-26), since monitoring was not attempted during pressure changes; however, resting data from bag collections were available, and these were used for calculations of M in subsequent tabulations (Tables 3, 7, and 8). Data from continuous monitoring, consisting only of $\dot{V}_{CO_2}$ recordings, were incomplete during the postdive SL control (days 28-30). These data, individual RQ averages, and resting data from bag collections were used to calculate energy expenditure during the postdive SL control period.

Average energy expenditure for 24 hours for all four subjects during the major periods of the dive is shown in Table 3. The second column shows that the hyperbaric condition caused daily energy expenditure to increase by 12%, and the hyperbaric condition plus cold caused it to rise 26% higher than control. The table also shows estimates of daily energy expenditure based on

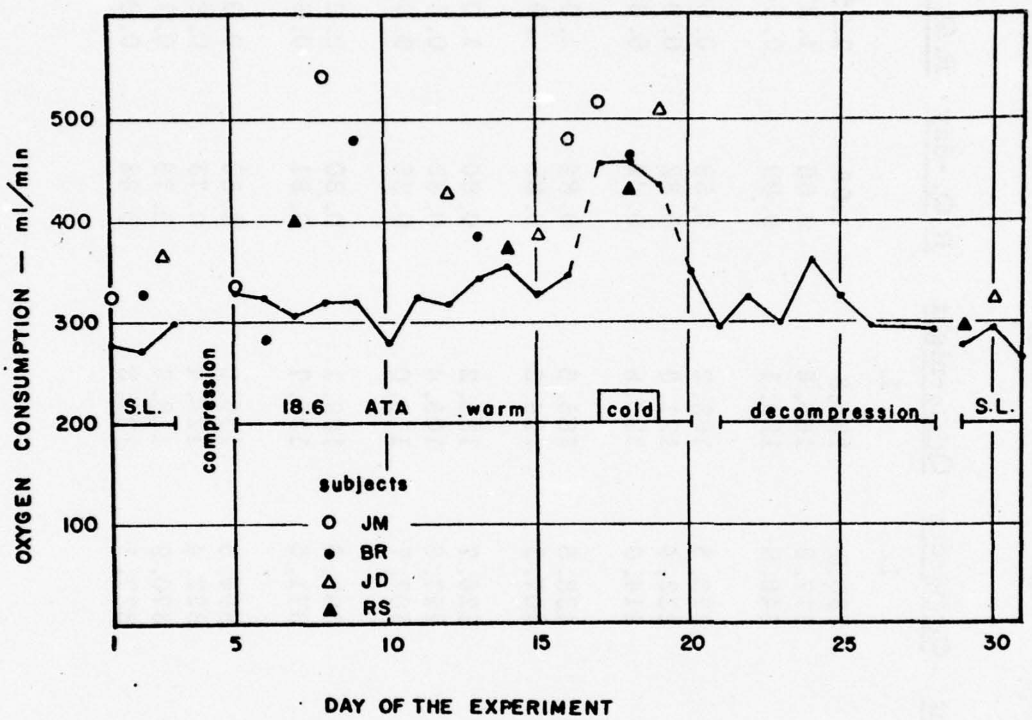

Figure 6. Two sets of oxygen consumption data shown as daily average levels, during the whole experiment. The small dots connected with a line are the average of four men measured four times daily seated at rest, using a conventional method of collecting exhaled air for three minutes. The large symbols are individual daytime (16 hour) averages for the same four men measured by the continuous monitoring method illustrated in Figures 3 and 4.

Table 2. Quantities of oxygen consumed (QO_2), carbon dioxide produced (QCO_2), and R.Q. from continuous monitoring; daily nitrogen excretion (N_{ur}); and daily energy expenditure (24-hr M).

Subj.	Dive day	Condition	QO_2-day	QO_2-night	QCO_2-day	QCO_2-night	R.Q.-day	R.Q.-night	Nur	24-hr M
			L	L	L	L			gms	kcal
JM	1	SL	312.1	137.7	330.8	130.3	1.06	0.95	14.93	2250
BR	2	control	315.5	122.4	277.6	155.6	0.88	1.27	8.63	2140
JD	3		349.5	131.0	346.8	123.1	0.99	0.94	9.19	2393
JM	5	18.6 ATA	319.0	121.0	275.5	108.2	0.89	0.90	15.13	2126
BR	6	warm	270.0	127.7	222.4	121.3	0.82	0.95	13.95	1917
RS	7		383.1	141.1	314.0	120.9	0.82	0.86	13.76	2517
JM	8		519.2	175.2	438.5	185.5	0.84	1.06	9.06	3407
BR	9		460.2	130.6	407.3	124.0	0.89	.95	15.39	2883
JD	12		408.4	129.1	326.7	134.2	0.80	1.04	15.60	2594
BR	13		359.5	122.5	297.6	105.4	0.83	0.86	15.35	2312
RS	14		358.0	132.7	307.7	119.0	0.86	0.90	20.15	2362
JD	15		369.4	114.3	295.6	109.1	0.80	0.95	16.60	2318
JM	16		460.1	143.7	371.6	135.7	0.81	0.94	12.74	2913
JM	17-19	18.6 ATA	495.6	144.4	396.5	136.9	0.80	0.95	17.82	3061
BR	17-19	cold	441.6	138.7	322.4	123.4	0.73	0.89	17.90	2742
JD	17-19		488.0	149.8	370.9	118.3	0.76	0.79	17.45	3017
RS	17-19		406.1	123.8	337.1	121.3	0.83	0.98	16.11	2560

Table 3. Mean energy expenditure of four subjects during the major experiment periods.

Period	Based on 24-hr monitoring: Daily level kcal	Based on 24-hr monitoring: Change from predive control %	Based on 4 resting, awake values daily: Daily level kcal	Based on 4 resting, awake values daily: Change from predive control %
Predive SL control (days 1-3)	2261	---	1989	----
18.6 ATA warm (days 5-16)	2535	+12	2207	+11
18.6 ATA cold (days 17-19)	2845	+26	3130	+57
Decompression (days 21-26)	---	----	2244	+13
Postdive SL control (days 27-30)	2142*	-5	2020	+2

*From $\dot{V}_{CO_2}$ data on two subjects.

the $\dot{V}_{O_2}$ and $\dot{V}_{CO_2}$ values from the bag collection method on seated resting subjects, using equation (7) and the 24-hr urinary nitrogen data. These resting values are generally lower than those from continuous monitoring, since the continuous 24-hr measurement covered non-resting daytime activity levels. Notice that the estimate of energy expenditure from bag collections in the cold 18.6 ATA condition is higher than that from continuous monitoring. The reason is that the nighttime $\dot{V}_{O_2}$ in cold was as low as it was in 18.6 ATA warm. In fact, nighttime levels in both warm and cold at 18.6 ATA were no higher than they were at sea level.

Food intake, fecal loss, and urine loss

Data on these three measurements are given in Tables 4 and 7. Table 4 shows the mean daily caloric values for food intake and fecal loss, as measured by bomb calorimetry. Food absorption was a normal 94-95% of food ingested. Urinary caloric values from bomb calorimetry are found in Table 7; these losses show a normal range of 2-4% of total calories ingested.

Table 4 also shows how accurate estimates of food intake are when the weights of specific food items are known and then converted to calories by using handbooks. Handbook values are adjusted by the "coefficient of digestibility," an estimate of food absorbed for each food type eaten, as derived from the Atwater system developed around the turn of the century. In the table, one should compare the values in column 3 (food absorbed) with those of column 4 (estimated food absorbed, from handbook values). The comparison shows the handbook method to be reasonably accurate, for the estimates differ from the measured values by +7%, +5%, and -10% for the three pairs of data shown.

Table 4. Mean daily values for food intake and fecal loss for five subjects in the major experiment periods.

Period	Food Intake kcal/day	Fecal Loss kcal/day	Food Absorbed kcal/day	Estimated Food Absorbed (Handbook) kcal/day
Predive SL control (days 1-3)	3586	220	3366	3588
18.6 ATA warm (days 5-16)	3210	205	3005	2846
18.6 ATA cold (days 17-19)	3826	208	3618	3269
Decompression (days 21-26)	3405	206	3199	----
Postdive SL control (days 27-30)	3895	226	3669	----
mean for 27 days	3440			

Change in body fat stores

Change in body fat stores was determined from: change in body weight; change in body density, hence body fat; change in TBW; and changes in skinfold thickness and torso circumferences. The density-body fat data were taken the day before the 3-day predive SL control, and the day after the postdive SL control, but the maximum changes in body weight occurred near the end of the 18.6 ATA exposure, followed by an evident regain of weight during the 7-day decompression and the 3-day postdive control period. Fortunately, we measured TBW at middive (9th day of 18.6 ATA warm), which helped to determine how much of the weight loss, or gain, was in fact from fluid rather than from body stores. Skinfold and circumference data were used only qualitatively to aid clinical judgment about whether fat stores were reduced, increased, or unchanged in a given subject.

The pertinent data are summarized in Table 5. It will be evident from this table that there were no large changes in body fat across the 30-day experiment, the range being from +0.9 kg to -2.5 kg. The general trend was toward loss of body fat, whether measured from weight change corrected for change in body water, or calculated from a combination of body density change and TBW. Subject JD neither lost nor gained, and subject RS gained throughout the 30 days. The apparent disagreements in the two methods of estimating must be ascribed to the inherent inaccuracies of the methods used, which Siri (1961) placed at about ±1.5% of body weight.

Table 5 also shows estimates for change in body fat from predive to middive, when TBW was remeasured. Again the trend is toward fat loss. The middive figure for subject RS (-2.4 kg) seems out of line, since he ate more for his size than anyone else, and since by other evidence he was gaining weight (fat) from the start.

Table 5. Changes in body weight and body fat by various procedures, for each of five subjects.

	Predive to middive				Predive to postdive				
Subj.	Δ wgt kg	Δ TBW kg	Δ body fat kg	Δ skin folds & circumfs.	Δ wgt	Δ TBW	Δ body fat*	Δ body fat**	Δ skin folds & circumfs.
JM	-1.2	-0.3	-0.9	decrease	0.4	0.8	-0.4	-0.3	decrease
BR	-2.0	-2.0	0.0	decrease	-1.5	0.8	-2.3	-2.5	decrease
JD	-0.9	-1.2	0.3	unchanged	0.5	0.5	0.0	0.0	unchanged
RS	0.4	2.8	-2.4	increase	2.2	2.7	-0.5	0.9	increase
EH	-1.4	-1.3	-0.1	decrease	-1.3	0.1	-1.4	-2.1	decrease
means:			-0.2				-0.9	-0.6	

*From (Δ body weight - Δ TBW).

**From changes in body density and TBW, by the method of Siri (1961).

We have assumed that body weight change, corrected for change in TBW, was due solely to change in body fat stores and not to change in glycogen stores or tissue proteins. Gycogen stores are thought to decrease significantly only during the first week of fasting, or of severe caloric restriction, and then only in the amount of 200-300 gms (Garrow 1974). In the present experiment, there was an excess of caloric intake over expenditure, which surely should have prevented loss of any of the glycogen store. As for the loss or gain in tissue protein, it seems unlikely that during the overfeeding and relative confinement of the experiment there should have been a significant loss of protein. The nitrogen balance data bear this out, for the men were in continuous positive N balance.

For purposes of calculating the contributions of fat stores to the energy balance of each man, all these data were considered carefully, and fat losses or gains apportioned to the different periods of the experiment. Thus in Table 6 we show our best estimate of the rather small changes in fat stores during the 12 days of 18.6 ATA warm and the three days of 18.6 ATA cold, as well as the total change from predive to postdive.

The values in Table 6 were multiplied by 7000 to convert kg of fat to kcal of energy (see Table 7). The conversion of pure fat to energy is 9000 kcal/kg, but fat, water, and some tissue are what is lost during weight reduction,, and the commonest multiplier is 6000 kcal/kg (Garrow 1974). Since we corrected our weight changes for TBW, and there was plenty of dietary nitrogen available, the 7000 kcal/kg seems a reasonable compromise.

Table 6. Changes in fat stores for various periods.

Subject	Predive control (3 days) kg	18.6 ATA warm (12 days) kg	18.6 ATA cold (3 days) kg	Predive to postdive (30 days) kg
JM	0	-0.7	-0.2	-0.3
BR	0	-1.5	-0.5	-2.5
JD	0	0	0	0
RS	0.1	0.3	0.1	0.9
EH	0	-1.5	-0.5	-2.0

Energy balances

In the preceding paragraphs we have considered the results of measuring all the terms in the energy balance equation, equation (6), which we rewrite using the conventional symbol M for metabolic free energy conversion instead of (Q_{O_2} x CEO_2):

$$M = CAL_{fd} - CAL_{fe} - CAL_{ur} + CAL_{st} \tag{8}$$

Table 7 presents the daily measured values for all of these terms, for each subject. Note that there are no values for M for subject EH, since he was not included in either method for measuring $\dot{V}_{O_2}$ and $\dot{V}_{CO_2}$.

We carried out the solution of equation (8) for the four men who had M values to check on how closely the data produced an energy balance. There was a consistent imbalance in that the total fuel (CAL_{fd} - CAL_{fe} - CAL_{ur} + CAL_{st}) regularly exceeded M, and by hundreds of calories. Incidentally, the sign convention in the above expression for total fuel means that when subjects were losing weight, they were drawing fuel from fat stores, hence adding to intake; similarly, since subject RS was gaining consistently, his value for CAL_{st} is shown with a minus sign in Table 7, since he was delivering some of his absorbed food to stores, not metabolizing it.

The situation is illustrated in Figure 7, in which mean values for energy expenditure and total fuel are shown for the several periods of the experiment. The differences in the heights of the columns show the consistent caloric imbalance observed.

Table 7. Daily values for the terms of the energy balance equation

A. Subject JM

Condition	Dive day	M kcal	CAL_{fd} kcal	CAL_{fe} kcal	CAL_{ur} kcal	CAL_{st} kcal
Predive SL control	1	2250	3414	228	126	0
	2		3270	228	142	0
	3		3517	228	132	0
means:			3400	228	133	0
18.6 ATA warm	5	2126	3944	259	125	408
	6		3817	259	133	408
	7		3282	259	145	408
	8	3407	3511	148	142	408
	9		2639	148	141	408
	10		4606	148	152	408
	11		4139	185	135	408
	12		2599	185	94	408
	13		2957	185	120	408
	14		3636	232	142	408
	15		2695	232	133	408
	16	2913	2935	232	124	408
means:		2815	3397	206	132	408
18.6 ATA cold	17		4672	184	144	467
	18	3061	4212	184	155	467
	19		4692	184	164	467
means:			4525	184	154	467
Decom-pression	21		3156	245	107	0
	22		3649	245	99	0
	23		4187	245	130	0
	24		2835	173	148	0
	25		4074	173	135	0
	26		3425	173	121	0
means:			3554	209	123	0
Postdive SL control	28		3751	212	164	0
	29		4024	212	61	0
	30		3209	212	116	0
means:			3661	212	114	0

Table 7., Continued

B. Subject BR

Condition	Dive day	M kcal	CALfd kcal	CALfe kcal	CALur kcal	CALst kcal
Predive SL control	1		3866	157	162	0
	2	2140	3225	157	138	0
	3		4314	157	86	0
means:			3802	157	129	0
18.6 ATA warm	5		3478	269	125	875
	6	1917	3716	269	126	875
	7		3320	269	102	875
	8		2394	147	126	875
	9	2883	2646	147	139	875
	10		3260	147	144	875
	11		2349	69	144	875
	12		2057	69	134	875
	13	2312	1830	69	126	875
	14		2713	187	153	875
	15		3082	187	153	875
	16		3293	187	143	875
means:		2371	2845	168	135	875
18.6 ATA cold	17		3793	203	---	1067
	18	2742	3171	203	152	1067
	19		3312	203	178	1067
means:			3425	203	165	1067
Decom-pression	21		3203	170	137	0
	22		3050	170	56	0
	23		3807	170	157	0
	24		3050	231	162	0
	25		3154	231	142	0
	26		3234	231	124	0
means:			3250	201	130	0
Postdive SL control	28		3508	247	159	0
	29		3942	247	139	0
	30		2913	247	106	0
means:			3454	247	135	0

Table 7., Continued

C. Subject JD

Condition	Dive Day	M kcal	CALfd kcal	CALfe kcal	CALur kcal	CALst kcal
Predive SL control	1		3945	318	135	0
	2		3433	318	148	0
	3	2393	4138	318	104	0
means:			3839	318	129	0
18.6 ATA warm	5		4008	179	90	0
	6		4536	179	123	0
	7		3956	179	114	0
	8		3440	140	133	0
	9		2835	140	133	0
	10		3196	140	125	0
	11		3912	216	135	0
	12	2594	3417	216	138	0
	13		2698	216	125	0
	14		2549	160	133	0
	15	2318	3329	160	125	0
	16		2907	160	128	0
means:		2456	3399	174	125	0
18.6 ATA cold	17	3017	3585	164	119	0
	18		3796	164	136	0
	19		4625	164	168	0
means:			4002	164	141	0
Decom-pression	21		3592	204	173	0
	22		2926	204	120	0
	23		4156	204	143	0
	24		2908	123	129	0
	25		3363	123	140	0
	26		4248	123	154	0
means:			3532	164	143	0
Postdive SL control	28		4257	253	93	0
	29		4989	253	91	0
	30	2253	4018	253	137	0
means:			4421	253	107	0

Table 7., Continued

D. Subject RS

Condition	Dive Day	M kcal	CAL_{fd} kcal	CAL_{fe} kcal	CAL_{ur} kcal	CAL_{st} kcal
Predive SL control	1		3188	155	117	-201
	2		3276	155	125	-201
	3		4007	155	92	-201
means:			3490	155	111	-201
18.6 ATA warm	5		4571	309	71	-201
	6		4158	309	86	-201
	7	2517	3671	309	149	-201
	8		3563	291	140	-201
	9		2862	291	126	-201
	10		3461	291	129	-201
	11		3670	137	149	-201
	12		3397	137	127	-201
	13		3618	137	125	-201
	14	2362	3662	278	179	-201
	15		4057	278	148	-201
	16		3460	278	94	-201
means:		2440	3679	254	127	-201
18.6 ATA cold	17	2560	3768	253	---	-201
	18		4094	253	148	-201
	19		4040	253	152	-201
means:			3967	253	150	-201
Decom-pression	21		3871	214	142	-201
	22		3673	214	99	-201
	23		3845	214	122	-201
	24		4170	326	104	-201
	25		3790	326	127	-201
	26		3433	326	126	-201
means:			3797	270	120	-201
Postdive SL control	28		4664	159	134	-201
	29	2031	4838	159	73	-201
	30		3518	159	112	-201
means:			4340	159	106	-201

Table 7., Continued

E. Subject EH

Condition	Dive Day	M* kcal	CALfd kcal	CALfe kcal	CALur kcal	CALst kcal
Predive						
SL control	1		3723	244	135	0
	2		2741	244	112	0
	3		3736	244	110	0
means:			3400	244	119	0
18.6 ATA	5		3429	289	102	875
warm	6		3838	289	104	875
	7		2915	289	114	875
	8		2764	130	128	875
	9		2118	130	97	875
	10		3145	130	119	875
	11		2984	218	157	875
	12		1884	218	107	875
	13		2070	218	114	875
	14		3009	256	152	875
	15		2615	256	135	875
	16		2698	256	152	875
means:			2789	223	123	875
18.6 ATA	17		3911	238	144	1167
cold	18		2907	238	165	1167
	19		2821	238	158	1167
means:			3213	238	156	1167
Decom-	21		2733	171	127	0
pression	22		2565	171	123	0
	23		3256	171	174	0
	24		2797	205	161	0
	25		2822	205	149	0
	26		3169	205	126	0
means:			2890	188	143	0
Postdive	28		4079	261	102	0
SL control	29		3349	261	116	0
	30		3363	261	129	0
means:			3597	261	116	0

*No M values were taken for Subject EH.

Table 8 contains the data from which Figure 7 was constructed. Mean values for M were the same as those shown in Table 3, from 24-hr monitoring. The one exception is the value for decompression, when no 24-hr monitoring was attempted; in this case the M value shown is based on the resting bag collection done four times a day. The numerical size of the imbalance is shown in the last column of Table 8. It amounts to about 30% of the total fuel (range 22 to 40% in the different periods). Stated simply, what we observe is that these four men consistently ate more than they expended, for the 30 days of the experiment.

Three days of the 30 were not tabulated (days 4, 20, and 27), since these were days in which data collection was incomplete. Food intake, urine, and feces were done as on all the other days, and the values were closely similar to those of the preceding and following days, so there is little liklihood that the imbalances of 27 days could have been somehow restored on the three days.

Also, we had complete data on subject EH -- food intake, urine and fecal collection, body composition and TBW -- but no measurements of M. Had we included his data along with the four others, using their mean values for M, the values for caloric imbalance would have changed very little.

The conclusion is inescapable: four, and probably five, subjects ate more than they spent, yet on the average they lost a little fat.

<u>Heat balance data</u>

The main value of the data in this category is to provide assurance that there was no major heat storage or heat loss, as would be indicated by high or low body temperatures. Figure 8 shows the daily mean values for

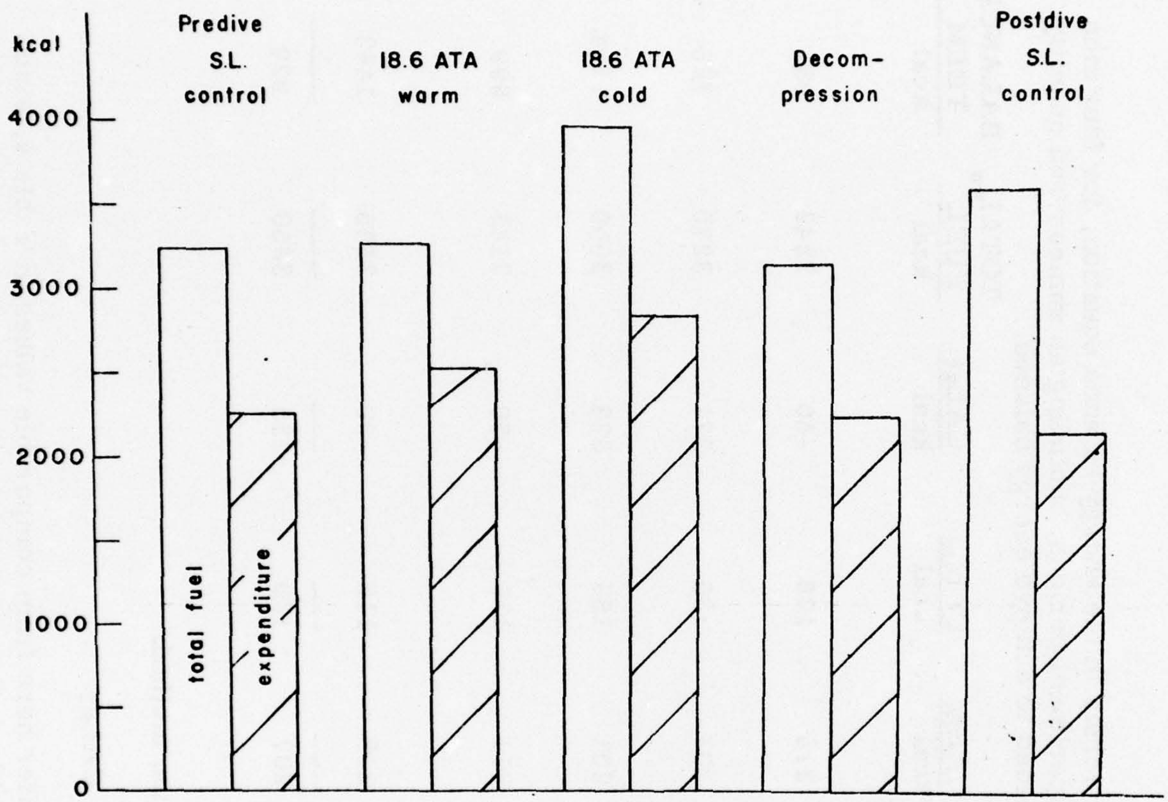

Figure 7. Average total fuel and expenditure for four men for the various experiment periods. Total fuel is food taken plus fat from stores, less waste in urine and feces. Expenditure is from oxygen consumption by continuous monitoring.

Table 8. Mean values for terms in the energy balance equation, for four men for all major experiment periods, including an unmeasured quantity needed to achieve energy balance.

Period	M kcal	CAL_{fd} kcal	CAL_{fe} kcal	CAL_{ur} kcal	CAL_{st} kcal	TOTAL FUEL** kcal	BALANCE TERM kcal
Predive SL control (Days 1-3)	2261	3633	215	126	-50	3242	981
18.6 ATA warm (days 5-16)	2535	3330	201	130	271	3270	735
18.6 ATA cold (days 17-19)	2845	3980	201	153	333	3959	1114
Decompression (days 21-26)	2244*	3533	211	129	-50	3143	899
Postdive SL control (days 27-30)	2142	3969	218	116	-50	3585	1443
Means for 27 days	2431	3552	207	130	135	3350	920

*Based on resting awake values by collection method.

**Total fuel is: $CAL_{fd} - CAL_{fe} - CAL_{ur} + CAL_{st}$

Note: The values for CAL_{fd} and CAL_{fe} differ here from comparable values in Table 4, since these are means for 4 men, while Table 4 shows means for 5 men.

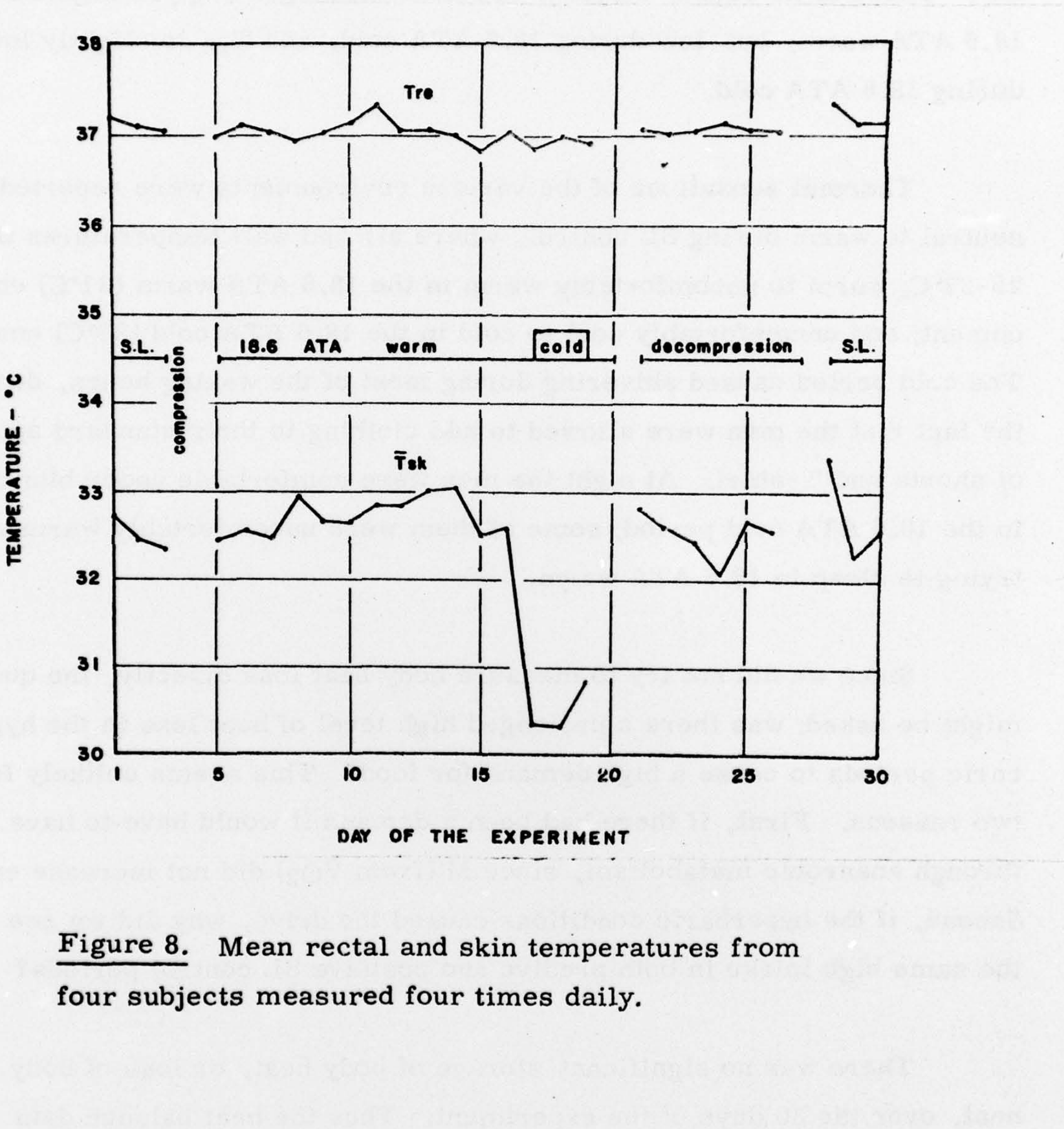

Figure 8. Mean rectal and skin temperatures from four subjects measured four times daily.

rectal temperature (T_{re}) and mean skin temperature ($\bar{T}_{sk}$). Each point is the mean of 16 measurements -- four men measured four times during the day. There is no sign of major heat loss or storage. $\bar{T}_{sk}$ is high during 18.6 ATA warm, but low during 18.6 ATA cold, and T_{re} is slightly low during 18.6 ATA cold.

Thermal sensations of the various environments were reported as neutral to warm during SL control, where air and wall temperatures were 25-27°C; warm to uncomfortably warm in the 18.6 ATA warm (31°C) environment; and uncomfortably cool to cold in the 18.6 ATA cold (27°C) environment. The cold period caused shivering during most of the waking hours, despite the fact that the men were allowed to add clothing to their standard apparel of shorts and T-shirt. At night the men were comfortable under blankets in the 18.6 ATA cold period; some of them were uncomfortably warm while trying to sleep in 18.6 ATA warm.

Since we did not try to measure body heat loss directly, the question might be asked: was there a prolonged high level of heat loss in the hyperbaric periods to cause a high demand for food? This seems unlikely for two reasons. First, if there had been a demand it would have to have been through anaerobic metabolism, since M (from $\dot{V}O_2$) did not increase enough. Second, if the hyperbaric conditions caused the drive, why did we see the same high intake in both predive and postdive SL control periods?

There was no significant storage of body heat, or loss of body heat, over the 30 days of the experiment. Thus the heat balance data do nothing to explain why there was the large caloric imbalance shown in Fig. 7 and in Table 8.

Convective heat transfer coefficient

Appropriate measurements were made to enable calculation of the convective heat transfer coefficient in the hyperbaric conditions. Since this is worth doing from empirical data, that calculation is now presented.

The calculation is conventionally based on the assumption that energy expenditure (M) is matched by the sum of all the heat losses over a period of time. The standard heat balance equation is given by Bligh and Johnson (1973) in the following form:

$$S = M \pm E - (\pm W) \pm R \pm C \pm K \qquad (9)$$

where: S is body heat storage;

M is metabolic free energy expenditure;

E is evaporative heat loss;

W is external or mechanical work; and

R, C, and K are radiative, convective, and conductive heat losses.

We can specify that S = 0 for a 24-hr period, since T_{re} and $\bar{T}_{sk}$ did not change from one morning to the next. Similarly, W was negligibly small, since exercise was infrequent and if taken was of brief duration. Also, K was negligibly small. This leaves M, E, R, and C, or, modifying equation (9):

$$S = 0 = M - (E + R + C), \text{ and} \qquad (10)$$

$$C = M - (E + R) \qquad (11)$$

We know the values for M from 24-hr monitoring (Table 3). Also, values for E were determined (from weight change corrected by the masses of oxygen and CO_2 exchanged) for both daytime and nighttime periods several times during the hyperbaric warm condition. The mean value for E for four men during the 16 hours of daytime at 18.6 ATA warm was

452 kcal; during the eight hours of night it was 178 kcal, making a total of 630 kcal/day. (The comparable values for SL control were: 650 kcal daytime, 244 kcal night, and 894 kcal/day.)

Radiative heat loss was calculated from the standard equation:

$$R = K_r A_r E_s (\overline{T}_{sk} - T_{gl}) \quad (12)$$

where K_r is the radiative transfer coefficient with a value of 7.0 kcal/hr-m^2-°C; A_r is the radiation area of the body, equal to .85 times the total surface area, which averaged 1.81 m^2 for the four men; E_s is the emissivity of the skin, with a value of 1.0; $\overline{T}_{sk}$ is the mean skin temperature; and T_{gl} is the globe temperature.

Equation (11) was solved for the 18.6 ATA warm and the 18.6 ATA cold conditions, to give a value for C in each case. The convective transfer coefficient, h_c, was then found by solving for it in the standard equation:

$$C = h_c (\overline{T}_{sk} - T_{gas}) A_b \quad (13)$$

where T_{gas} is the ambient gas temperature, and A_b is the total body surface area, with a value of 1.81 m^2 for our four men.

The measured data for solving equations (11) and (13) are given in Table 9. The result was:

at 18.6 ATA warm (31°C): h_c = 20.7 kcal/m^2-hr-°C

at 18.6 ATA cold (27°C): h_c = 9.1 kcal/m^2-hr-°C

Table 9. Measured data for heat transfer equations (means of multiple measurements on four subjects over several days)

	M kcal/day	E kcal/day	$\bar{T}_{sk}$ °C	T_{gl} °C	T_{gas} °C
18.6 ATA warm	2535	630	32.7	30.9	31.1
18.6 ATA cold	2845	630*	30.5	27.3	27.0

*No separate data available for 18.6 ATA cold; it should be lower, because of lower $\bar{T}_{sk}$.

Nitrogen balance

Nitrogen balance data are summarized in Table 10. All five subjects were in positive nitrogen balance over 27 days of the 30-day experiment (three days were not calculated because of incomplete data), although there were occasional single days when a given man would show a negative balance. Subject JM had the most days of negative balance, 10 in 27, and subject RS the least, one day in 27.

DISCUSSION

There was a small overall weight loss for the five men in Hana Kai II, yet net caloric intake was high -- higher than energy expenditure. Thus the general picture in Hana Kai II was similar to that of the other dives listed in Table 1. The weight loss of saturation diving occurs despite high food intake.

None of the plausible explanations offered in the introduction seems to be the right one. The first proposed that a large increase in energy expenditure would require the high food intake and still need more fuel, which would be drawn from body fat deposits. In Hana Kai II, M increased, but never equalled total fuel, as shown in Fig. 7. The second explanation was that weight loss might result from water loss and not from fat loss, but our data on total body water do not permit this explanation. There was the possibility of tissue loss from the atrophy of disuse; a positive nitrogen balance ruled this out. Fourth was the possibility that food eaten was poorly digested and absorbed, but our data showed that fecal losses were a normal 4-8% of intake, as reported in Tables 4 and 7. Finally, we postulated some unidentified error in caloric balance data of earlier dives, e.g. an overestimation

Table 10. Nitrogen in food, feces and urine in grams/day, and nitrogen balance. Values are means, standard deviations, and range for 27 days.

Subject	Nitrogen in food gm			Nitrogen in Feces gm			Nitrogen in Urine gm			Nitrogen balance gm		
JM	18.1	±4.6	(9.3-26.5)	2.2	±0.4	(1.8-3.1)	14.8	±3.7	(4.3-20.7)	1.1	±5.3	(-8.3-11.8)
BR	19.3	±3.4	(9.8-23.4)	2.1	±0.7	(0.6-3.3)	13.7	±4.1	(3.5-21.2)	3.5	±5.7	(-7.2-16.8)
JD	22.8	±3.9	(16.1-31.4)	2.2	±0.7	(1.3-3.5)	15.0	±2.7	(9.2-19.4)	5.6	±4.8	(-1.9-18.0)
RS	21.3	±3.2	(14.7-27.9)	2.4	±0.6	(1.4-3.1)	13.3	±3.4	(7.0-20.2)	5.5	±5.3	(-1.1-18.2)
EH	20.2	±3.8	(8.7-25.6)	2.4	±0.7	(1.3-3.3)	12.3	±3.2	(6.6-17.3)	5.5	±5.0	(-5.7-14.4)
Grand means	20.3			2.3			13.8			4.2		

of calories taken, but our data do not support this possibility. In fact, we have shown that handbook values for calories in food, as used in previous studies, are not wrong by more than about ± 10%.

The 18.6 ATA warm condition did stimulate metabolism, for the resting $\dot{V}_{O_2}$ and the 24-hr $\dot{V}_{O_2}$ values were 11 and 12% higher respectively than those for SL control. Metabolism rose further when the temperature of the 18.6 ATA gas was dropped from 31 to 27°C. But it is obvious from the data that the increase in energy expenditure was far smaller than either the food intake or the total fuel. Food intake seemed high for the low level of physical activity caused by the confinement of the hyperbaric chamber. The subjects stated that they were eating more than they usually ate, but we have no control measurements on their food intake for normal living conditions outside the chamber. Since the men ate a great deal even during SL control, it is possible that the high food intake of saturation diving is not the result of the hyperbaric condition, but rather a reaction to the boredom of confinement, or to being the object of study.

The most striking finding was the consistent need for an additional quantity in energy balance to explain the results. Roughly 900 kcal/day was needed to balance the energy equation for each man, each day for 30 days (Table 8). That is, on average the five men consumed about 900 kcal more each day for 30 days than they spent. They should have stored as adipose tissue the 27,000 kcal, or 3.86 kg apiece. Instead, they lost a little weight. They were overeating, yet three of the five drew fuel from body stores.

The imbalance between intake and expenditure seems at first glance to be similar to what is called "luxuskonsumption," in which an increase of food intake for many weeks, under sea level conditions in a metabolic ward, is not accompanied by weight gain; there may even be occasional single weeks of weight loss, as reported by Miller and Mumford (1967). In their experiments, subjects ate 1400 kcal/day more than their usual intakes over a 4-week period and gained 2.4 kg instead of the calculated 5.2 kg of adipose tissue. But where the traditional explanation of luxuskonsumption is that the extra calories are disposed of by a matching increase in heat production (Miller et al. 1967), in our experiment there is no comparable increase. The daily 900 kcal/man is an excess of total fuel over expenditure. If the 900 kcal/man-day was being lost because of the greater capacity of the hyperbaric environment to remove heat, then that extra heat did not come from oxidation of fuel, i.e. it is not seen in M.

The heat balance calculation we used to compute the convective heat transfer coefficient, h_c, was similar to that used by others except that we used 24-hr data since it was available, and it seemed safer to assume that body heat storage would be zero over such a long period. Comparison of our values for h_c with those predicted by previous workers shows that our value of h_c in 18.6 ATA warm, 20.7 kcal/m^2-hr-°C, agrees with the 20.4 kcal/m^2-hr-°C predicted by Raymond et al. (1975), while our value for h_c in 18.6 ATA cold of 9.1 kcal/m^2-hr-°C agrees with the 9.8 kcal/m^2-hr-°C predicted by Raymond et al. (1968), and also is not far from the value of 11.4 kcal/m^2-hr-°C predicted by Timbal et al. (1974). There is no obvious reason why h_c should be higher in warm hyperbaric conditions than in cold. Our calculations contain some error in overestimating the evaporative heat loss term in cold, the effect of which would be to increase h_c for the cold case. There are other possible sources of error, like the procedure for measuring skin temperature in less clothing than the men wore during much of the day and night. All heat balance calculations are to some degree suspect.

It is only rarely that energy balance studies are undertaken with the thoroughness of the present one. We did so because of the intriguing finding from previous saturation dives -- a high food intake associated with weight loss. We fully expected that the 24-hr measurement of M, from $\dot{V}_{O_2}$, $\dot{V}_{CO_2}$, and urinary N, plus measurements of weight, total body water and body composition, along with direct measurements of the calories in food feces and urine, would provide an explanation of the weight loss. It was disappointing that our measurements did not explain what happens. Food intake was high indeed, but not apparently because of the hyperbaric condition; intakes were high also during the pre- and postdive control periods, as they were during compression and decompression. Expenditure rose a little during the comfortably warm 12 days at 18.6 ATA, then rose higher during the cold three days at 18.6 ATA, but the increases failed to come close to matching the total fuel measured for these times, or for the whole experiment.

There should be no doubt that energy balance exists, under both hyperbaric and ordinary conditions. Our results strongly suggest that there is a large energy term which is not measured by conventional techniques.

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